

SPECTRAL IMAGING FOR REVEALING AND PRESERVING WORLD CULTURAL HERITAGE

Fenella G. France, Michael B. Toth

Preservation Research and Testing Division, Library of Congress
101 Independence Ave, SE, 20540-4560, Washington D.C., United States of America
phone: + (1) 202-707-5525, fax: + (1) 202-707-1525, email: frfr@loc.gov
web: <http://www.loc.gov/preserv/rt/projects/index.html>

ABSTRACT

The utilization of spectral imaging for the preservation of cultural heritage has allowed the Library of Congress to develop and adapt methodologies to reveal information from degraded ancient texts and objects. Spectral imaging systems provide a powerful tool for non-invasive, non-contact identification and characterization of pigments, inks, substrates and treatments of artefacts, allowing completely non-destructive analyses for research and preservation. Detecting any changes before they are visible enables the assessment and optimization of display and storage conditions for a range of heritage materials. Advanced processing of significant manuscripts including the Waldseemüller 1507 World Map, Jefferson's draft of the Declaration of Independence, and others have revealed previously non-visible and obscured information, recovering lost scientific and cultural knowledge that forms the basis of modern society.

1. INTRODUCTION

At the Library of Congress the application and development of hyperspectral imaging for the preservation of cultural heritage materials and analysis of historic documents provides a powerful technique for assessing collection objects [1]. This utilizes an imaging system that captures the spectral response of materials from the ultraviolet, visible and near infrared regions of the spectrum (UV-VIS-NIR) and also reveals obscured information. The Library imaging system comprises a MegaVision 39 Megapixel monochrome camera (7216 x 5412) E6 back, and APO-Digitar 5, 6/120 lens, integrated through customized software with light emitting diode (LED) illumination panels that span the spectral range of 365nm to 1000nm for reflected, transmitted and raking (side-lighting) imaging modes. The non-destructive spectral imaging can be used to characterize historic documents by capturing the unique chemical spectral response of composite materials; including substrates (paper, parchment, photographic materials) and media (inks, pigments, colorants) [2]. Capturing UV, VIS and NIR spectral data in various illumination orientations minimizes handling of fragile items and allows greater capacity for materials analysis and post-acquisition processing to uncover hidden and obscured text and information [3]. All images are accurately registered in a data cube, enabling almost unlimited combinations of spectral wavebands for further processing. A filter wheel for fluorescence and polar-

izing has been integrated into the system to expand the current imaging capabilities.

This advanced imaging of heritage documents allows greater access to the object and enhances non-visible obscured information in registered high resolution digital images. In addition to spectral identification of materials, this non-contact tool can be used to monitor storage and exhibition changes or deterioration in parchment, paper and other materials due to environmental conditions, and assess treatments of historic documents that may change the response of layers of text and annotations.

Critical developments of the Library imaging program include the development of a spectral reference database, the integration of data from other non-invasive analytical techniques, and a full analytical mapping of objects for non-destructive analyses of collection materials. The resulting cube of spectral data acquired creates a new "digital cultural object" that is related to, but distinct from the original. Coordinating the relationship between these two entities enables greater access to scholarly information since identification of materials enables provenance, geographical (spatial) and temporal information to extend knowledge about the historic document, without the requirement for samples to be taken. The range of data this digital *object* contains enhances interaction across a range of professions, allowing multidisciplinary collaboration for integration of preservation, sociological and cultural information. The digital representation of the original analog object balances preservation and access to the original, requiring a rigorous process of standardized processing, extensive archival metadata and data management.

Advances in lens properties, sensor and illumination technology have significantly advanced the field of spectral imaging. These developments have been enhanced through improvements in customized image capture software, and standardized image capture and image signal processing techniques [4]. While the Library endeavoured to utilize open source software, the need for a standardized product led to analysis and comparison of a range of freely available and off-the-shelf image processing software packages including ENVI™. Due to the complexity of cultural heritage documents for image analysis, more developed spectral processing software has provided the required results, and the ability to install and utilize robust and sophisticated digital processing algorithms. With its ability to spectrally classify materials and map the distribution of historic cultural materials over the surface of

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2011		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Spectral Imaging For Revealing And Preserving World Cultural Heritage				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Preservation Research and Testing Division, Library of Congress 101 Independence Ave, SE, 20540-4560, Washington D.C., United States of America				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADA589869. European Signal Processing Conference (19th) (EUSIPCO) Held in Barcelona, Spain on August 29-September 2, 2011					
14. ABSTRACT The utilization of spectral imaging for the preservation of cultural heritage has allowed the Library of Congress to develop and adapt methodologies to reveal information from degraded ancient texts and objects. Spectral imaging systems provide a powerful tool for non-invasive, non-contact identification and characterization of pigments, inks, substrates and treatments of artefacts, allowing completely non-destructive analyses for research and preservation. Detecting any changes before they are visible enables the assessment and optimization of display and storage conditions for a range of heritage materials. Advanced processing of significant manuscripts including the Waldseemüller 1507 World Map, Jeffersons draft of the Declaration of Independence, and others have revealed previously non-visible and obscured information, recovering lost scientific and cultural knowledge that forms the basis of modern society.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

heritage materials, hyperspectral imaging has begun to be used as a first point of examination for all Library collection items. This provides a baseline for identifying where visually similar but spectrally different compounds are located, as well as revealing layers of information in the historic documents. Spectral mapping is also useful for suggesting where complementary instrumentation techniques should be utilized to complete examinations.

2. THE WALDSEEMULLER 1507 WORLD MAP

The Waldseemüller 1507 World Map was the first map, (printed or manuscript) to refer to America, sometimes referred to as America's birth certificate. The copy at the Library of Congress is the only known survivor of the 1,000 copies of the map believed to have been printed. Martin Waldseemüller's world map grew out of a project in St. Dié, France to document and update new geographic knowledge derived from previous discoveries, including data gathered during Amerigo Vespucci's voyages to the New World. The Waldseemüller map was the first map to clearly depict a separate Western Hemisphere, with the Pacific as a separate ocean, and represented a huge leap forward in knowledge [5]. Waldseemüller carved 12 woodblocks that were used to print the twelve separate sheets of the map. Each of the sheets of laid paper measured approximately 61 x 46 cm and since the map was designed to be assembled as a wall-map, the finished map measured approximately 2.4 metres wide by 1.4 metres high. The exchange between the German Government and the Library of Congress requires that the map always be on exhibit for anyone to view. The large anoxic display encasement was designed to maintain a 20-30 year hermetic seal, so the decision was made prior to encasement to use hyperspectral imaging to capture extensive historical information for researchers and scholars.

Over time, inscribed red grid lines on sheets six and seven had faded significantly and were virtually imperceptible. These grid lines represented important added features in the cartographic history of this map, so it was important for curatorial collaborators to find a way to retrieve this lost information. Johannes Schöner (1477-1547), a German astronomer and cartographer and pupil of Waldseemüller, was noted to have drawn red lines over the Middle East north to the Black Sea, an area that must have been of interest. With the spectral imaging, these lines could be separated and distinguished through their unique spectral response. Image processing of the spectral information enabled the recreation of the grid lines by using the specific spectral response of the red colorant and creating a pseudocolour image. This reconstruction allowed researchers to assess overlapping of the lines, which lines were laid down first, where lines began and ended, and began to broaden the interpretation and understanding of Schöner's thought processes from the early 1500s. As shown in Figure 1, principle component analysis (PCA) from a 12 band image cube and pseudocolour combination of bands 1, 2 and 3 enabled further enhancement of the lines to more accurately assess overlays, and interactions with other components of the map.

While the Waldseemüller 1507 world map is famous for the first reference to 'America', it remains a source of intrigue since the cartographer is known, but not the precise time or location of printing [6]. It is suggested that the Waldseemüller 1507 map was bound to a large extent by Ptolemaic tradition.



Figure 1 – PCA enhancement of faded map grid lines

The map was discovered in 1901 by Joseph Fisher, a Jesuit historian conducting research in the library collection of Wolfegg Castle, Wurttemberg, Germany. He was convinced that the World Map sheets were printers' proof sheets, so the ability to gain greater understanding about how the woodcut was produced was of great interest to scholars, cartographers and historians. Specialized processing, utilizing images taken with the side-lighting panels in the VIS (blue) and NIR regions (470 and 910nm respectively), created a virtual 3D rendering of the map, giving a visual perspective of what the original woodcut that the sheets were printed from may have looked like (Figure 2). Since the original woodcut no longer exists, the processed images allow an analysis of possible techniques used in the early 1500s to inform scholars about creation techniques and gain a better understanding of the materials used in the process.

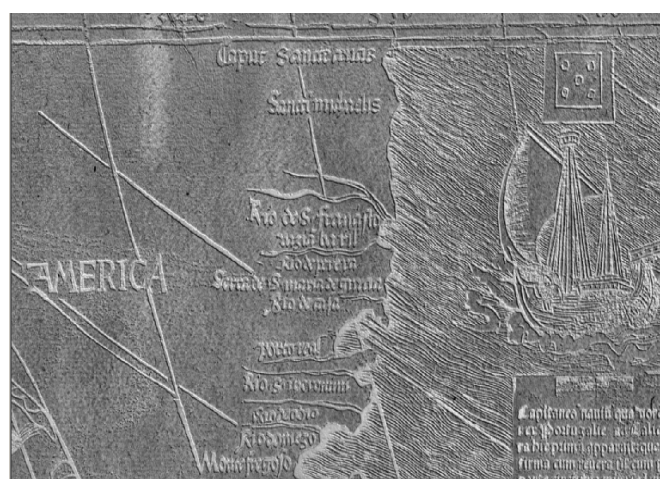


Figure 2 – Depiction of appearance of the original woodcut features

Other signal processing included a PCA spectral separation of an iron gall ink inscription most likely added by Schöner,

as shown in Figure 3. The image processing clearly illustrates the iron gall ink writing on top of the printing ink.

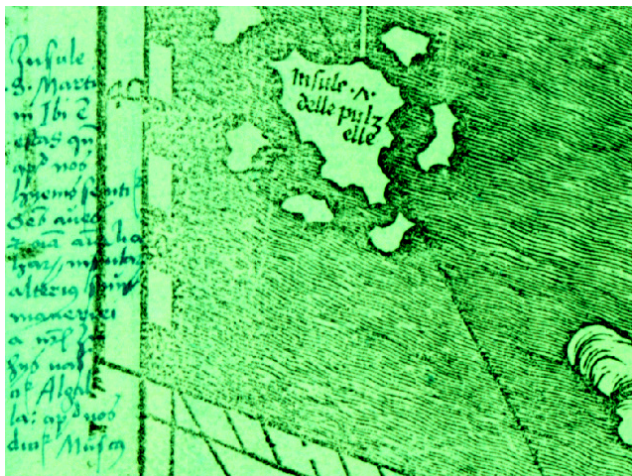


Figure 3 – PCA of printing and iron gall ink inscription (sheet 10)

Other obscured historical information included revealing the text of a prayer book on a pastedown on sheet 12 of the map. This text on the reverse of a piece of paper adhered to this sheet of the map was made visible in the NIR (870nm) as illustrated in Figure 4.

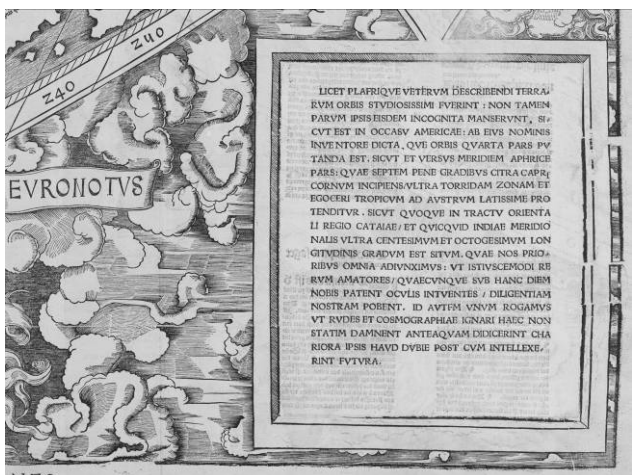


Figure 4 – NIR hidden text rendering on pastedown (sheet 12)

Additional image acquisition and processing was undertaken to capture the selection of watermarks on the map sheets. The detection of watermarks has long been undertaken by a variety of methods, the most preferred method being beta radiograph plates [7]. Due to health concerns by the Safety Division, the Library sought a new method that would continue to provide the same quality as that of the beta radiograph plates. Ongoing studies utilizing the combination of reflected and transmitted techniques have enabled the capture of heavily obscured watermarks while retaining the requisite chain and laid line dimensionality. Image processing has enabled the suppression of the overlaying text, facilitating the enhancement of the watermark features, including the chain and laid lines. This had been a challenge with the imaging given that

the chain and laid lines often are perceived as “noise” by the software.



Figure 5 – Comparison of beta radiograph and unprocessed transmitted light imaging of one of the map watermarks

3. JEFFERSON'S HANDWRITTEN DRAFT OF THE DECLARATION OF INDEPENDENCE

Thomas Jefferson's handwritten rough draft of the United States Declaration of Independence epitomizes how new technologies continue to add knowledge to documents that have been examined at length by generations of researchers. The "original rough draught" of the Declaration of Independence is one of the significant documents and milestones in American history. This document demonstrates the evolution of the text from the initial "fair copy" draft by Thomas Jefferson to the final text adopted by the Second Continental Congress on the morning of July 4, 1776. Thomas Jefferson wrote this first draft with amendments from Dr. Franklin and Mr. Adams, since they were the two members of the committee he wished to benefit from in regards to their judgment on content [8]. This was the first time the term “United States” had been used in an official document, and sets the world context for the cultural influence of this document post-1776, with meanings that varied as widely for American as they did for international audiences [9].

One of the challenges with the imaging of historic documents is the dearth of information about previous conditions and treatments they may have undergone. These previous treatments such as lamination, silking and varnishes can interfere with spectral imaging, providing a more diffuse reflective surface. This can impact focus through the entire UV-VIS-NIR range, and challenges for separation of text based upon the spectral composition.

Spectral imaging of the handwritten draft revealed a number of changes, with the specific spectral response of inks illuminating overwritten changes. As Jefferson noted, any changes or amendments were specifically annotated and attributed to each person involved in the drafting of the document. However there is one region where an obvious “smudge” of the under-text hints at the presence of a previous word. Imaging processing of this region proved challenging, given that the document was laminated and the inks were spectrally very

similar in composition. Figure 6 below illustrates image processing with subtraction of bands 10-5 (NIR, green visible) image inversion and overlay.

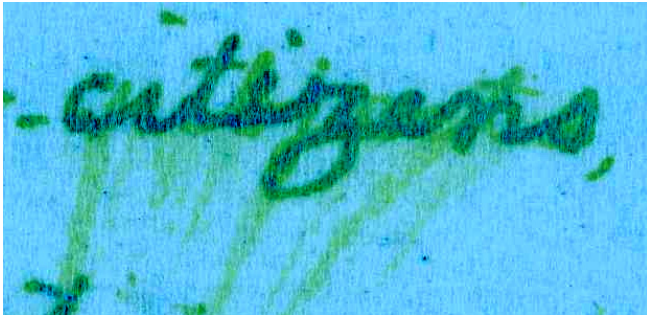


Figure 6 – Initial processing of underlying text

As illustrated in Figure 7, it was finally revealed that Thomas Jefferson had originally written “fellow-subjects” and changed this to “fellow-citizens”. This word correction had been suspected for some time, with a researcher from Princeton University noting that Jefferson was copying the term from the First Draft of the Virginia Constitution, rapidly erasing this while the ink was still wet on the ‘Rough draught’ and carefully covering it with the word ‘citizens’ [10]. This immediate and deliberate overwrite is the only location on the entire document where a hasty change is apparent, and a deliberate attempt to completely expunge the original writing. Everywhere else in the draft document changes are both neatly crossed out and clear insertions made. If the change or insertion was not suggested by Jefferson, he carefully notes this in the margin. Further evidence of the care taken with ascribing the changes is evidenced with pencil underneath written over in ink for other insertions and ascriptions.

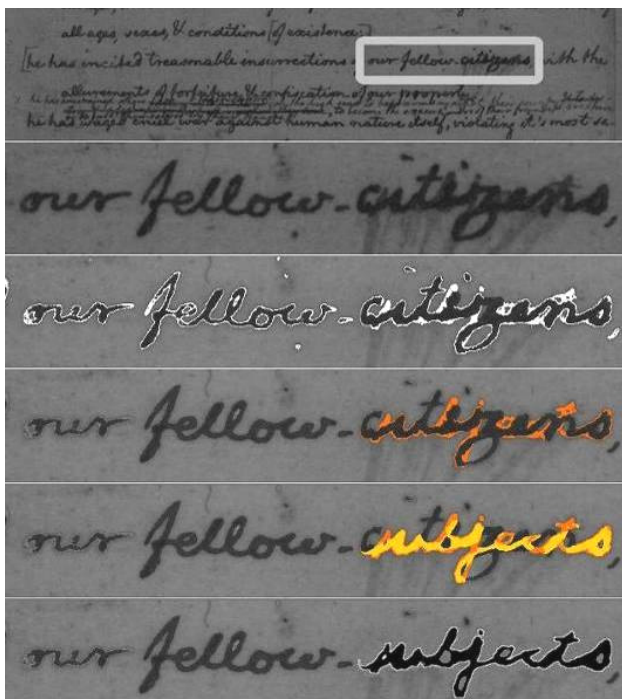


Figure 7 – Declaration of Independence “subjects to citizens”

Processing included taking the difference between two bands (IR and visible) to difference imaging and ratios between wavebands with an Otsu multi-threshold technique to enhance different intensity ranges. Pseudocolours were assigned and transition edges removed, to allow the “joining of the dots” with the word “citizen” made equal to the background text to be essentially removed for clarity of viewing.

4. OTHER HISTORIC DOCUMENTS

Each historic document reveals its own unique changes and previously unknown information. The first drafts of the Gettysburg address illustrate variations from the patterns observed in the Jefferson draft. The Gettysburg shows minimal changes in the text, suggesting a careful thought process, and previous thought – the work of one person rather than a collaborative effort. There is however an abrupt and obvious change in the use of materials. Both media and substrate alter, as Abraham Lincoln crossed out three words at the bottom of the first page written on Executive Mansion stationery, and began writing in pencil rather than ink, and the second page is a torn foolscap blotter page. This raises questions as to whether this was simply the only materials he had available – a forced choice – since there have been claims this was written on the train on the way to or at Gettysburg, or a deliberate choice in that this was seen as temporary and he expected to make further changes [11]. There is considerable debate about where Abraham Lincoln wrote this text, with a number of publications suggesting various scenarios. Processing of images can show the intensity of an author's writing, similar to assessing an artist's brush-strokes, and this is an area that can assist in determining who wrote historic documents in a time when scribes were taught to retain a very similar style of writing. Figure 8 illustrates the capacity for the imaging to capture the intensity of the authors writing, allowing further insights into thought processes of the author. The speech underscores the importance of history and the meticulous attention to detail in weighing the impact of every word. All the words used are short, simple every-day language, with repetition to emphasize and create meaning.

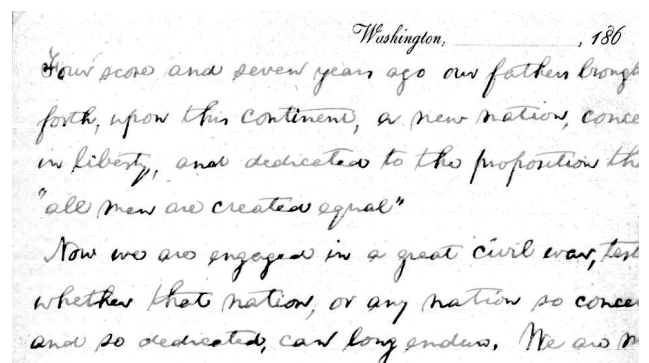


Figure 8 - Section of the Gettysburg Address (Nicolay Copy) Illustrating Ink Intensities

Portolan, (early nautical charts) from 1320-1633 have been imaged to analyze layering of information on the charts and non-invasive colorant identification. Spectral curve analysis led to characterization of colorants. The data cube was com-

pared with reference colorant samples, normalizing the reflectance illumination to remove interference from the paper substrate due to colorants only being present in a very thin wash. After generating a stack from the data cube, the specific spectral regions of interest were selected, and a spectral curve unique to that material was generated. For spectral unmixing this required determining end-members of pure pigments before the combination curves can be generated. For the 1320 Portolan chart vermillion was identified from a “pixel” sample taken from the image that corresponded to a reference sample, as illustrated in figure 9.

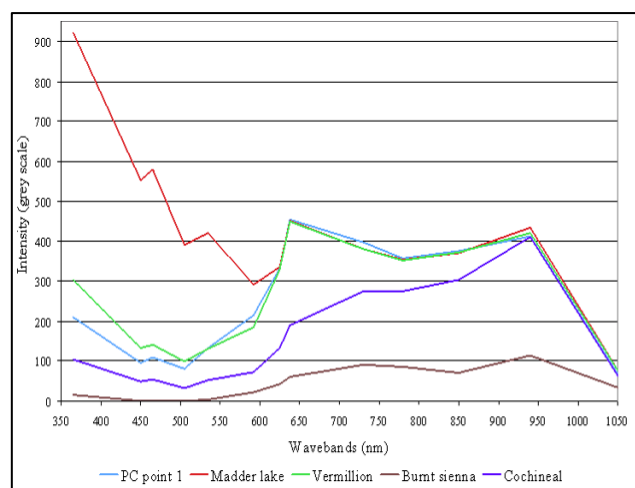


Figure 9 – Non-Invasive Spectral Identification of Colorants

Non-invasive spectral characterization of colorants and other compounds on the surface of historic documents allows analysis, differentiation and identification of colorants that otherwise appear visually identical, while providing the capacity to identify areas showing deterioration of colorants, corrosive inks and substrate (paper or parchment). These deterioration changes can be tracked through baseline imaging compared to data collected from subsequent imaging that allows the optimization of conditions for historic materials.

5. CONCLUSION

The utilization of spectral imaging serves as an initial examination and analysis tool for historic documents, revealing a range of previously unknown information and data. A standardized approach to image acquisition procedures and processing parameters has taken spectral imaging from sophisticated remote sensing capabilities to an easily accessible laboratory tool for the preservation and scholarly analysis of historic cultural materials. The development of image acquisition parameters that control the imaging environment have served to minimize any impact on fragile cultural heritage objects and manuscripts. Spectral imaging that encompasses the UV-VIS-NIR spectral regions cover an extensive range of potential materials characterization and the wide-reaching recovery of lost and hidden information. These modalities offer the potential to capture large amounts of data for later processing and analysis to address preservation, scientific analysis and scholarly interests.

The transfer of technology from multidisciplinary fields has demonstrated huge potential for the cultural heritage arena, particularly in the expansion of non-invasive analyses. This reiterates the utilization of this new modality for addressing the preservation of the original object – both substrate and media – since the recovery of obscured information and insights into construction techniques from previous centuries would not have been possible had the original object not been preserved. Spectral imaging has a two-pronged approach – information to preserve the original, and recovering and acquiring baseline information should further irreversible deterioration occur.

A continued focus on collaboration between people, data and processes is a major factor in promoting access and integration of scientific, scholarly and humanities research, emphasizing the importance of linking the original artefact with digital tools and techniques for visualizing and disseminating new knowledge in the arts and humanities. The benefits of non-invasive imaging techniques ensure that significant historic documents can be analyzed before there is further loss of information, allowing access for current and future generations.

REFERENCES

- [1] C. Fisher, and I. Kakoulli, “Multispectral and hyperspectral imaging technologies in conservation: current research and potential applications”, *Reviews in Conservation*, 7, 3-16 (2006).
- [2] D. Goltz et. al., Assessing stains on historical documents using hyperspectral imaging, *Journal of Cultural Heritage*, Vol. 11 19–26, 2010.
- [3] F.G. France, Eikonopoiia: “Spectral imaging and non-invasive characterization of manuscripts” Symposium on Digital Imaging of Ancient Textual Heritage, Helsinki, Finland, 2010, pp. 51-64.
- [4] R. L. Easton et. al., Standardized system for multispectral imaging of palimpsests, *SPIE*, , San Jose, CA, USA, pp. 75310D-1-75310D-11, 2010.
- [5] J.W. Hessler, *The Naming of America*, Giles, London, United Kingdom, 2008.
- [6] E. Harris, “The Waldseemüller Map – A typographic appraisal” *Imago Mundi*, Vol. 37, pp. 30-53, 1985.
- [7] N.E. Ash, AIC: The Book and Paper Group, 1982, <http://cool.conservation-us.org/coolaic/sg/bpg/annual/v01/bp01-02.html>
- [8] I.M Hays, “A note on the history of the Jefferson manuscript draught of the Declaration of Independence”, *Proc. of the Amer. Philosophical Scty*, Vol. 37, No. 157, pp. 88-107, 1898.
- [9] D. Armitage, “The declaration of independence in world context”, *OAH Magazine of History*, Vol. 18, No. 3, pp. 61-66, 2004.
- [10] J.P. Boyd, *The Papers of Thomas Jefferson, Volume 1: 1760-177*, Princeton University Press, 1950.
- [11] Library of Congress, *Long Remembered: The Gettysburg Address in the handwriting of Abraham Lincoln*, The Library of Congress, Washington D.C., USA, 1963